

# Open Research Online

---

The Open University's repository of research publications and other research outputs

## Developing design as a discipline

### Journal Item

How to cite:

Cross, Nigel (2018). Developing design as a discipline. Journal of Engineering Design, 29(12) pp. 691–708.

For guidance on citations see [FAQs](#).

© [not recorded]



<https://creativecommons.org/licenses/by-nc-nd/4.0/>

Version: Accepted Manuscript

Link(s) to article on publisher's website:

<http://dx.doi.org/doi:10.1080/09544828.2018.1537481>

---

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

---

[oro.open.ac.uk](http://oro.open.ac.uk)

## Developing Design as a Discipline

*Nigel Cross*

School of Engineering and Innovation, The Open University, Milton Keynes, UK.

### Abstract

*This is an invited paper reviewing my personal design research history, covering 50 years of involvement since the mid-1960s. The focus of my research has shifted over time, from computer aided design and design methodology to design epistemology and design cognition. In CAD I assessed its effectiveness and implications for design professions, and how AI research in design might inform understanding of design cognition. In design methodology I developed a model that integrates procedural aspects of design process with structural aspects of design problems. In design epistemology I developed concepts of designerly ways of knowing and design as a discipline. In design cognition I conducted protocol studies of design activity and studied design expertise, and developed the concept of the co-evolution of problem and solution. A general progression in the work has been from aiding and supporting design practice towards more fundamental understanding of design as a discipline.*

**Keywords:** *design cognition, design computing, design epistemology, design methodology, design research.*

### Prologue

In my senior years at school I studied mathematics and physics, and I was intending to be an engineer (thinking especially of automotive design engineering). On leaving school in 1960 I began an engineering apprenticeship as part of a Technology Diploma course in Mechanical Engineering at the (then) Bristol College of Science and Technology. I enjoyed the practical apprenticeship work, but I found the academic course very dull (much of it felt like repeating the maths and physics I had already studied at school). I think that I had expected an engineering course to include some designing, but it didn't. In the same college, a new architecture course had started a few years prior, and the architecture students seemed to be having a much more interesting and creative time! So I applied to enter the architecture course. Despite my lack of qualifications in art I was accepted, and started the following year. There, I discovered there was a lot of studio design time but little actual design teaching - we were given design projects to do, and the tutors then 'critiqued', or criticised, our designs. Although we were shown, and encouraged to look at, examples of good architecture, I thought it odd that we were never taught *how* to design. Since they were not teaching us how to design I didn't see how they could reasonably criticise our designing!

Around 1963 I became aware of the new work in design methods, arising from the 1962 Conference on Design Methods (Jones and Thornley, 1963), which I thought might

offer a more rational approach to designing. For my final year 'Thesis Project' in the architecture course I chose to design a large (for the UK at that time) state secondary school. In designing the school, I tried to use Christopher Alexander's method for 'the synthesis of form' (Alexander, 1964), but found I could not even start to compose the requirements statements that it needed, let alone do the detailed linking work between them. I knew someone at the other school of architecture in Bristol who was doing postgraduate work in CAD, including floorplan-layout programs, and I asked him to produce a basic 'least circulation cost' layout of the main accommodation groups that I had defined for the school. It didn't really have much influence on the final design, but the computer-produced layout gave me a sort of rational design starting-point. I had overcome some of my concerns about 'how to' design, and I got a very good final 'crit' assessment for my project. At the start of that final year (1965-66), the College was being reorganised and upgraded into Bath University of Technology. As a result, we final-year architecture students were told we would get a BSc degree rather than the previous Diploma. That was lucky for me, because it gave me the entry requirement for the Masters course in Industrial Design Technology run by J. Christopher Jones at the University of Manchester Institute of Science and Technology (UMIST). I went to the course because I wanted to learn more in the new topics such as design methods and computing, but the course was also a good general research training.

From there, I went on to an academic career, with my research interests gradually developing from helping to support design through CAD and design methods, towards investigating and understanding more fully 'how to design', and the nature of design thinking and design expertise. I have grouped aspects this work into four themes in the following sections: design computing, design methodology, design epistemology, and design cognition.

## **1. Design Computing**

My first research project was my MSc project at UMIST in 1967 on 'Simulation of Computer Aided Design'. This was based on a novel and strange idea that we might get some insights into what CAD might be like, and what the design requirements for CAD systems might be, by attempting to simulate the use of CAD facilities, which at that time were mostly hypotheses and suggestions for future systems that hardly anyone really knew how to develop (Sutherland's seminal but very basic 'Sketchpad' interactive system had only been developed in 1963). The strangeness in this idea was that these simulations could be effected through getting human beings to pretend to be the computers. This was a kind of reverse application of the 'Turing Test' for artificial intelligence, and which later became known as a 'Wizard of Oz' research method in human-computer interaction design.

The project was based on asking designers (architects) to attempt a small design project in experimental conditions. They were given the design brief, and asked to produce a sketch design. As well as conventional drawing materials, they had a simulated computer system to help them: they could write questions on cards located in front of a closed-circuit TV camera, and would receive written answers (or even drawings) on a TV screen in front of them. In another room, at the other end of the CCTV link, was a small team of architects and building engineers who attempted to answer the designer's questions. Thus we had a very crude simulation of some features of what might be parts of a CAD system, such as expert systems and databases. The designers who participated in these experiments were not told what to expect from the 'computer', nor given any

constraints on the kinds of facilities they might choose to ask of it. I hoped to discover what kinds of facilities and features might be required of future CAD systems, and gain some insights into the behavioural patterns that might emerge in these future human-computer systems.

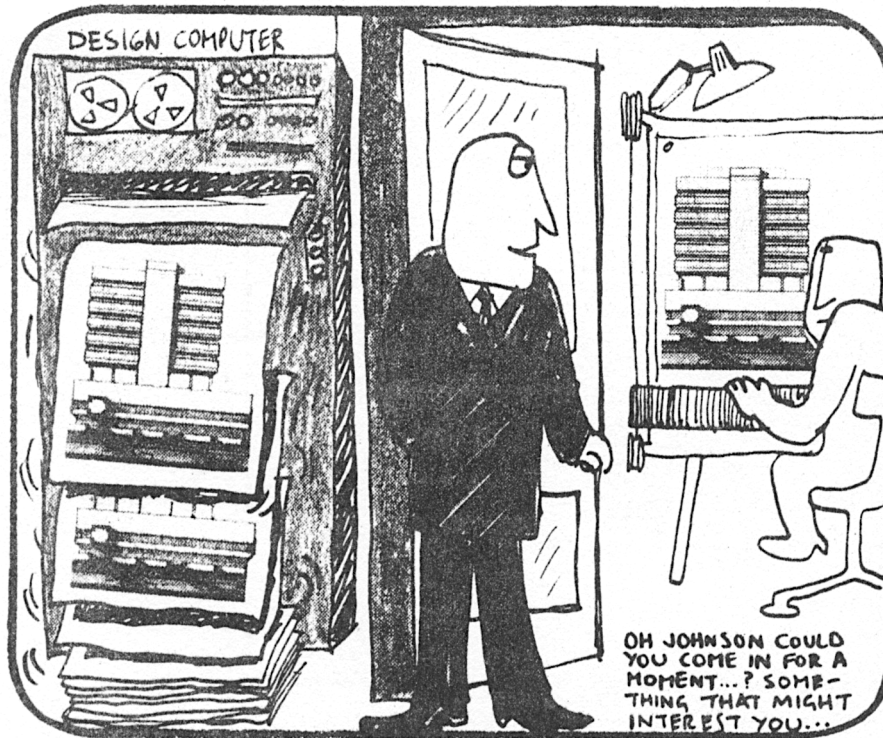
I conducted ten such experiments, each of which lasted about one hour. The messages between designer and 'computer' were recorded, and one of the analyses I made was to classify them into the topics to which they referred, from the client's brief to construction details. This kind of data gave some insight into the designers' patterns of activity. The number of messages sent in each experiment was quite low, with normally several minutes elapsing between requests from the designer. Of course, the response time from the 'computer' could also be quite long, typically of the order of 30 seconds. Despite this slow and apparently easy pace of interaction, in de-briefing interviews all the designers reported that they found the experiments hard work and stressful. They reported the main benefit of using the 'computer' as being an increased speed of work, principally by reducing uncertainty (i.e. they relatively quickly received answers to queries, which they accepted as reliable information).

I also tried a few variations from my standard experiments. The most interesting of these was to reverse the normal set of expectations of the functions of the designer and the 'computer'. The 'computer' was given the job of having to produce a design, to the satisfaction of the observing designer. It was immediately apparent that in this situation there was no stress on the designer - in fact, it became quite fun - and it was the 'computer' that found the experience to be hard work. This led me to conclude in my dissertation that CAD system designers should aim for an active, rather than a passive role for the computer:

The computer should be asking questions of the designer, seeking from him those decisions which it is not competent to handle itself. The computer could be doing all the drawing work, with the designer instructing amendments ... We should be moving towards giving the machine a sufficient degree of intelligent behaviour, and a corresponding increase in participation in the design process, to liberate the designer from routine procedures and to enhance his decision-making role.

Unfortunately, 50 years later, I don't think that vision has yet been accomplished, although current parametric CAD modelling in architecture, allied with advances in structural engineering, does seem to have allowed architects (for better or worse) to exercise more freedom of imagination in what can be designed and built.

My studies had suggested that using computers in design might have adverse effects, such as inducing stress, on designers. The only positive effect that CAD appeared to have was to speed up the design process. The potential negative effects of CAD that I identified were an intensification of the designer's work rate and a concomitant reduction in the person-power required in design offices (Figure 1). But on the other hand I suggested that CAD in architecture might lead to better communication between members of the design team, and to the inclusion of a wider range of participants, such as the building's users (Cross, 1972a). This potential of CAD for de-professionalising the design process, allowing laypeople to design for themselves, using 'architecture machines' (Negroponte, 1970), featured strongly amongst contributions to the proceedings of the first international conference of the Design Research Society, on Design Participation, which Chris Jones, Reg Talbot and I organised in 1971 (Cross, 1972b).



*Figure 1*

A cartoon by Louis Hellman illustrating the comment in my article in *The Architect's Journal* on the impact of computers on architectural design: 'It can now be seen that savings will be made at middle management level which, in an architectural practice, is probably at the level of, or just below, job architect.' (Cross, 1972a) [Louis Hellman/RIBA Collections]

Nevertheless, I also still had a largely positive belief that computers might produce designs that are somehow better - more efficient, or more elegant, or something - than designs produced by humans. I continued research on investigating the issue of human and machine roles in computer aided design for my PhD (Cross, 1974). Drawing on research in problem solving (of the 'travelling salesman' route-layout type) at the pioneering artificial intelligence centre at Edinburgh University, I expected that human-machine interaction could produce design solutions that were better than either a human or a machine could produce alone. So I tested that hypothesis, using the problem of efficient room layouts in a building plan. I devised experiments in which fully-automatic computer programs, un-aided designers, and designers aided by interactive layout programs tackled the same layout problems.

I fully expected to replicate the Edinburgh results in favour of effective problem-solving through human-machine interaction, and was genuinely surprised to find that (a) there were no significant differences between the performances (i.e. the efficiency of the layouts) of un-aided designers and automatic computer programs, and (b) human-machine interaction produced worse results than either un-aided humans or automatic machines! There were some strong mitigating circumstances arising from the crude nature of the human-machine interaction that was possible at that time (teletype terminals and storage-tube displays), but nevertheless it was a surprising result, that shook my confidence in CAD developments at that time, and led me to the conclusion that computer aided design might actually make design results worse, rather than better. In expanding my thesis for publication in book form (Cross, 1977a), I concluded that CAD would be of very limited positive effectiveness as a design aid, but could have

profound negative effects on design activity and the job of being a designer. In an article in the Journal of the Royal Institute of British Architects, I confessed that 'I have seen the future; and it doesn't work!' (Cross, 1977b)

However, the developments in computing and CAD throughout the 1980s made me realise that, for good or bad, using computers in design practice was inevitable (indeed was already becoming ubiquitous), although I continued to be dubious about the personal and social impacts of computers within design. In some of my research I also found that computational models of design activity can be useful descriptive or explanatory models of human design behaviour. This has been particularly so in the field of creative design, where attempts to build computational models have provided some useful paradigms for the nature of creative design activity.

In 1998 John Gero invited me to join an international workshop celebrating 30 years of design computing at the University of Sydney, Australia. I still had some doubts about the personal and social impacts of computer use within the design professions, and so I chose to reflect on the question 'Can a machine design?'. I suggested that

We might not necessarily want machines to do everything that human beings do, but setting challenges for machines to do some of the cognitively hard things that people do should give us insight into those things and into the broader nature of human cognitive abilities. I had always assumed that this argument was one of the validations for research in artificial intelligence. Thus we would learn more about ourselves. For example, the research programme in computer chess playing has presumably not had the ultimate aim of making it unnecessary for humans ever to 'need' to play chess again. Rather, it has been to gain understanding of the nature of the 'problem' of the chess game itself, and of the nature of the human cognitive processes which are brought to bear in chess playing and in the resolution of chess problems. (Cross, 2001a, p. 48-49)

I concluded that

[R]esearch in artificial intelligence should always address the question, 'What are we learning from this research about how people think?' Similarly, our computer-design research should attempt to tell us something about how designers think. I believe we can learn some important things about the nature of human design cognition through looking at design from the computational perspective ... For me, the value of asking the question 'Can a machine design?' is that it begs the corollary question, 'How do people design?' (Cross, 2001a, p. 50)

The important question for me was really 'What is it that people are doing when they are doing design?' My work in design computing had begun with attempts to create more efficient and rational design processes in architecture, but had moved towards a view that computerisation of architectural design might introduce more efficiency in design practice but would have little positive effect on the quality of the end product, and could well have detrimental effects on the job satisfaction of architects. I had also realised (as had others who had been involved in the early developments) that there was much more involved in designing good architecture than producing 'efficient' plans. My interests moved from assisting design through CAD and artificial intelligence to seeking to understand more about the 'natural intelligence' of design thinking (Cross, 1999) and the creative skills of designers. I was still bothered about 'how to design'.

## **2. Design Methodology**

In 1970, I joined Chris Jones at the new UK Open University (OU), where he had been appointed to the Chair of Design in the Technology Faculty. The small academic

departments that were set up initially in the OU were called 'Disciplines', so we were the Design Discipline and were faced for the first time with the challenge of developing design as a discipline. At the same time, we had to face the challenge of conducting design education at a distance, through the media of TV, radio and print, and in a context of general, mass education, rather than the selective, profession-orientated, studio-based education of traditional design schools.

Chris Jones had just published his book *Design Methods: Seeds of Human Futures* (Jones, 1970), which not only provided a textbook of methods but also an expanded view of design as a broad, futures-creating activity. In producing our first design courses, this work proved apposite: design methods externalised some of the activities of designing and could be taught in an explicit way, and a broader, non-profession-orientated view of design was relevant in the context of the OU, where students were not studying for a specific, professional qualification. One of the first teaching texts I produced for the OU, with Robin Roy (another ex-student of Chris Jones), was a *Design Methods Manual* (Cross and Roy, 1975), which was also well-received outside the OU, and I still get people in the design world telling me how influential it was for them.

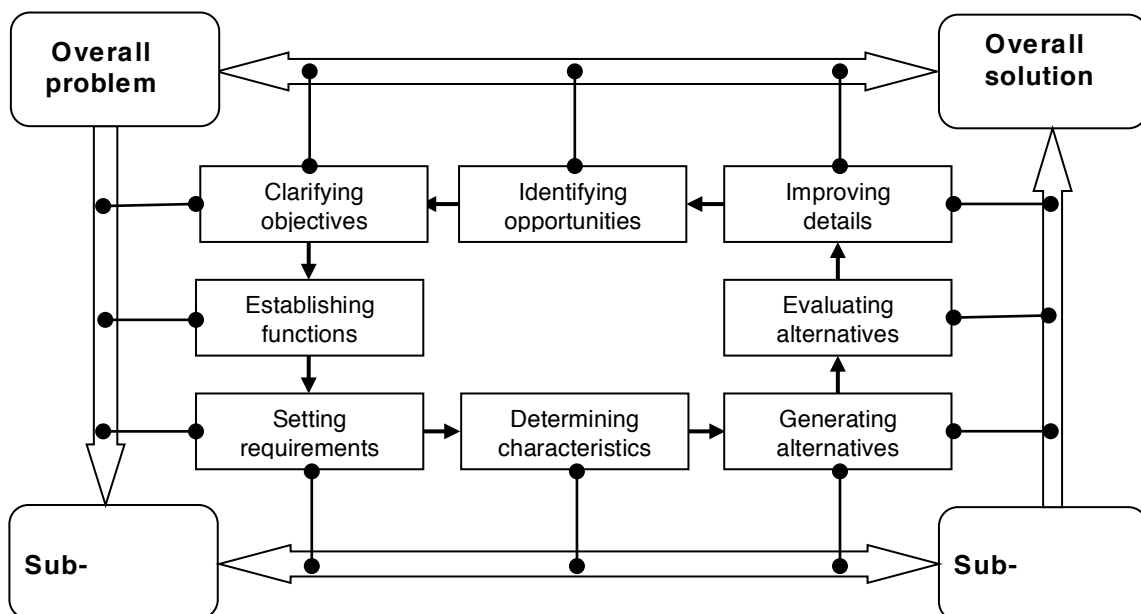
At conferences of the Design Research Society in the late 1970s and early 1980s I realised that a new generation of researchers was appearing, who had only limited awareness of the origins of design research and methods. This was not surprising, because the development of the field up until then had been conducted primarily through conferences and isolated research papers. For newcomers, there was no easy way by which they could become familiar with the field and its history of development. So I put together a reader of *Developments in Design Methodology* (Cross, 1984) covering what I considered to be the important, influential papers from the first 20 years of that development since the 1962 Conference on Design Methods.

As I noted in the introduction to the reader, to prepare such a book on design methodology at that time 'would seem to be either a very brave or foolish thing to do', because during the 1970s there had been a backlash against methodology (including even from leading design methodologists, such as Alexander and Jones) and 'methodologists are reviled as impoverished creatures who merely study, rather than practise, a particular art or science'. Part of the distrust of methodology might arise from an ambiguity in the use of the word. In the sense of 'a methodology' it can be used to mean a particular, prescribed, rigid approach, of which practitioners are usually sceptical. But the broader, and more correct sense of the word is to mean the general study of method. Anyone who wishes to reflect on how they practise their art or science (or designing), and anyone who teaches others to practise, must draw on methodology. Design methodology therefore is the study of the principles, practices and procedures of design in a rather broad and general sense. Its central concern is with how designing both is and might be conducted. This concern therefore includes the study of how designers work and think, the establishment of appropriate structures for the design process, the development and application of new design methods, techniques and procedures, and reflection on the nature and extent of design knowledge and its application to design problems.

I went on to publish another book on *Engineering Design Methods* (Cross, 1989; now in its 4th edition, 2008). The book was designed to be more than a manual of procedures; there was also discussion of the principles, processes and practice of design. Individual methods are presented in the book as tactics, to be used selectively within an informed, strategic approach for designing successful products. Many designers are suspicious of

design methods, fearing that they are a 'straitjacket', stifling creativity. This is a misunderstanding of the intention of design methods, which are meant to improve the quality of design decisions, and hence of the end product. Both creative methods and rational methods are complementary aspects of an informed approach to design. Rather than a 'straitjacket', they should be seen as a 'lifejacket', helping the designer, especially the student designer, to keep afloat in the complex currents of a design project.

In the book, the use of design methods is structured around a process framework that matches problem finding with solution generating. This is a hybrid model that attempts to integrate the predominantly prescriptive, linear, rational models of engineering design with the descriptive, spiralling, cognitive models developed in industrial design and architecture (as discussed in Cross and Roozenburg, 1992). This model (Figure 2) assumes a symmetrical, commutative relationship between problem and solution, and between sub-problems and sub-solutions, but recognising also that there should be some logical progression from problem to sub-problems and from sub-solutions to solution.



*Figure 2*

This model of designing integrates the procedural aspects of design with the structural aspects of design problems. The procedural aspects are represented by the sequence of eight methods (anti-clockwise, in the inner loop, from the top), and the structural aspects are represented by the arrows showing the commutative relationship between problem and solution and the hierarchical relationships between problem/sub-problems and between sub-solutions/solution. (Cross, 2008)

Although intended primarily for students of engineering and industrial product design, I wrote in the introduction to my design methods book that I hoped it might also be useful 'as an introduction to design for the many teachers and practitioners in engineering who found this subject sadly lacking in their own education' (as I did, at the beginning of the 1960s, in my own brief introductory education in engineering).

For a conference in 1992 I wrote a paper (Cross, 1993) reviewing the history of design methodology and its relationship with science. The origins of design methods in the 1950s and '60s had lain in 'scientific' methods of planning and management, such as decision theory and operations research. I distinguished between three science-design



relationships: scientific design, design science and a science of design. The reasons advanced for developing new methods of design were often based on an assumption that modern, industrial design had become too complex for intuitive methods. The originators of the design methods movement of the 1960s realised that there had been a change from pre-industrial design to industrial design - and perhaps even to post-industrial design. The first half of the 20th century had also seen the rapid growth of scientific underpinnings in many types of design, such as materials science, engineering science, building science, and behavioural science. So I suggested that all modern, industrialised design (as distinct from pre-industrial, craft-orientated design) is *scientific design*, based on scientific knowledge but utilising a mix of both intuitive and non-intuitive design methods.

A desire to 'scientise' design can also be traced further back to ideas in the modern movement of design in the 1920s, but the term 'design science' became especially associated with the originators of the ICED conferences, the Workshop Design Konstruktion (WDK) or The International Society for Design Science (now The Design Society). The concern to develop something that could be regarded as design science led some to attempts to formulate *the* design method - a single rationalised method, based on formal languages and theories. This is extending beyond 'scientific design' to include systematic knowledge of design process and methodology as well as the scientific/technological underpinnings of the design of artefacts. So I suggested that *design science* refers to an explicitly organised, rational and wholly systematic approach to design; not just the utilisation of scientific knowledge of artefacts, but design in some sense as a scientific activity itself.

This view of a design science remains controversial in some quarters, especially those in which design is seen as different from but equal to science as a human activity. This different view embraces the development of a 'science of design', which seeks to understand and improve designing but without it having to be channelled into a technical-rational, scientific activity. In this view, therefore, the science of design is the study of design - something similar to what I defined as 'design methodology': the study of the principles, practices and procedures of design. So I concluded that the *science of design* refers to that body of work which attempts to improve our understanding of design through scientific (i.e., systematic, reliable) methods of investigation.

In his book *The Sciences of the Artificial*, Herbert Simon laid out a positivist, technical-rational view of design theory and practice, but he also went so far as to say that 'the proper study of mankind is the science of design' (Simon, 1969, p. 83). (The phrase is a corruption of the line 'the proper study of mankind is man' in an 18th century poem by Alexander Pope.) What Simon was suggesting was that a science of design could be a fundamental, interdisciplinary and integrative study, and furthermore 'not only as the professional component of a technical education but as a core discipline for every liberally educated man' (*ibid.*). (Presumably he meant, and should have written, 'every liberally educated person'.) It is this fundamental view of a science of design, reaching across all domains of design, and relevant and accessible to all, that underlies my work in understanding the nature of design thinking and practice.

### 3. Design Epistemology

As well as the establishment of the Open University, the 1970s saw another important, widening development of design education in the UK, as it gradually became adopted as a subject within secondary schools. Bruce Archer, one of the other pioneers of design

methodology with Alexander and Jones (Archer, 1965), became deeply involved in this development, and set up a new Design Education Unit alongside his Design Research Department at the Royal College of Art, London, to help develop the theory and practice of design education. He also obtained funding from the UK government for a research project around 'Design in General Education', with a goal 'to provide the means for achieving a level of design awareness in the general community analogous to literacy and numeracy' (Archer, 1979a). This was the radical view of design as 'a third area of education', alongside, and equal with, sciences and humanities, which Archer had outlined earlier in a 1976 speech on 'The Three Rs'.

These developments of design in general education chimed well with our task at the OU of creating a non-professional education in design, and also provided some support for the concept of design as a discipline. I began a research programme on design epistemology, seeking in particular to link research and theory in design methods and processes with fundamental educational principles and theory. In this, I was helped considerably by my wife, Anita Clayburn Cross, an educationalist who also worked with Bruce Archer at the RCA. Anita contributed particularly on identifying the intrinsic values of design education and the concept of a design intelligence (Cross, A. C., 1984, 1986). At the same time, within the Design Research Society I had been working with others to set up a journal of design research, which launched in 1979 as *Design Studies*. As one of the editors, I initiated a series of articles on the theme of 'Design as a Discipline', as a means of helping to promote, understand and articulate the concept. In the first issue of the journal we reprinted Archer's 'The Three Rs' speech as the first in the series (Archer, 1979b). The second in the series was 'A Timeline Theory of Planning and Design' by Gerald Nadler (Nadler, 1980). For the third, I wrote 'Designerly Ways of Knowing' (Cross, 1982).

This paper, which built on Archer's work at the RCA and our work at the OU, developed the criteria that design must satisfy to be acceptable as a part of general education, and to stand as an independent 'third area'. Such an acceptance would imply a reorientation from the instrumental aims of conventional, professionally-orientated design education, towards intrinsic values of design as a valid subject of study for everyone. These intrinsic values, I argued, must derive from the deep, underlying patterns of how designers think and act. Because they share a common concern with these fundamental 'ways of knowing', both design research and design education could jointly contribute to developing design as a discipline. I also suggested that this emerging view of 'designerly ways of knowing' could form an axiomatic 'touch-stone theory' for research within design as a discipline.

The 1980s saw a significant shift in perspectives on design thinking, from criticising the apparent limitations of design practice to recognising the inherent strengths and potential of design cognition, or 'how designers think' (Lawson, 1980). In particular, Donald Schön established his theory of reflective practice as a counter to the theory of technical rationality as the predominant, or preferred approach to resolving practical problems (Schön, 1983). Schön sought a new 'epistemology of practice' that would help explain and account for how competent practitioners actually engage with their practice – a 'kind of knowing' which is different from the knowledge conventionally found in textbooks. In his analysis of the case studies across different professions (including architecture and engineering) that provided the examples for his theory, he began with the assumption that 'competent practitioners usually know more than they can say. They exhibit a kind of knowing-in-practice, most of which is tacit.' He identified a cognitive

process of reflection-in-action as the intelligence that guides 'intuitive' behaviour in practical contexts of thinking-and-acting.

For my inaugural lecture as Professor of Design Studies at the Open University in 1989, I prepared a paper on 'The Nature and Nurture of Design Ability' (Cross, 1990). The first part of the paper concentrated on the nature of design ability, for which I drew upon previous studies of design activity and designer behaviour. In the second part of the paper I argued that understanding the nature of design ability is necessary in order to enable design educators to nurture its development in their students. I summarised design ability as comprising abilities of resolving ill-defined problems, adopting solution-focussed cognitive strategies, employing abductive or appositional thinking and using non-verbal modelling media. These abilities are highly developed in skilled designers, but they are also possessed in some degree by everyone, and therefore can and should be part of everyone's education. I went on to outline a case for design ability as a fundamental form of human intelligence, thus seeking to provide a much broader foundation for establishing the concept of 'designerly ways of knowing'.

This interpretation of design thinking as a form of intelligence was based on the work of psychologist Howard Gardner. Gardner's view is that there is not just one form of intelligence (as conventionally identified in standard forms of 'intelligence tests'), but several, relatively autonomous human intellectual competences (Gardner, 1983). He distinguished six forms of intelligence:

- linguistic
- logical-mathematical
- spatial
- musical
- bodily-kinaesthetic
- personal.

Aspects of design ability are found spread throughout these various forms of intelligence in a way that does not always seem entirely satisfactory. For example, spatial abilities in problem-solving (including thinking 'in the mind's eye') were classified by Gardner under spatial intelligence, whereas many other aspects of practical problem-solving ability (including examples from engineering) were classified under bodily-kinaesthetic intelligence. So in this classification, for example, the inventor's competence is placed together with that of the dancer and the actor, which doesn't seem appropriate. It would seem reasonable, therefore, to try to separate out design ability as a form of intelligence in its own right.

Gardner's criteria for the recognition of a distinct form of intelligence were as follows:

- Potential isolation by brain damage.
- The existence of *idiots savants*, prodigies and other exceptional individuals.
- An identifiable core operation or set of operations.
- A distinctive developmental history, and a definable set of expert, end-state performances.
- An evolutionary history.
- Susceptibility to encoding in a symbol system.
- Support from experimental psychological tasks.

In my inaugural lecture, I summarised some of the evidence for design intelligence against these criteria, and I concluded that, 'If asked to judge the case for design intelligence on this set of criteria, we might have to conclude that the case is "not

proven". Whilst there is good evidence to meet most of the criteria, on some there is a lack of substantial or reliable evidence.' Thirty years later we actually have much more of that evidence, thanks to the growth of design research with a focus on design thinking. This research includes evidence for 'isolation by brain damage' (Goel and Grafman, 2000), work on the 'core operations' (e.g. Gero, 1990; Lawson, 1994; Dorst and Cross, 2001; Dong, 2009), on 'expert performance' (e.g. Bucciarelli, 1994; Cross and Clayburn Cross, 1998; Cross, 2004; Lawson and Dorst, 2009), on 'symbol systems' (e.g. Goldschmidt, 1991; Schön and Wiggins, 1992; Goel, 1995; Purcell, 1998), and on protocol studies and other 'experimental psychological tasks' (e.g. Cross, 2001b; Visser, 2006; Alexiou et al., 2009).

Whatever the current strength of the case may be, viewing design thinking as a form of intelligence seems to me to be a productive view; it helps to identify and clarify features of the nature of design thinking, and it offers a framework for understanding and developing design ability through design education. A view of design thinking as a distinct form of intelligence does not necessarily mean that some people 'have it' and some people do not. Design ability is something that everyone has, to some extent, because it is embedded in our brains as an evolved cognitive function. Like other forms of intelligence and ability it may be possessed, or may be manifested in performance, at higher levels by some people than by others. And like other forms of intelligence and ability, design intelligence is not simply a given 'talent' or 'gift', but can be trained and developed.

Much of my work in design epistemology was brought together in the book *Designerly Ways of Knowing* (Cross, 2006, 2007). The book traces the development of the research programme over a period of some 20 years, from the 'Designerly Ways of Knowing' paper of 1982 to a more fully developed argument for 'Design as a Discipline', based on a science of design, for a design research conference in 2000 (Cross, 2001c). A key insight for me at the start of this programme was to realise that if we wanted to develop a robust, independent discipline of design (rather than let design be subsumed within paradigms of science or the arts), then we had to be much more confident and knowledgeable about the particular nature and qualities of design activity, design knowledge, and design cognition.

#### **4. Design Cognition**

In 1990 I joined the Faculty of Industrial Design Engineering at Delft University of Technology as Professor of Design Methodology. There, I was to work closely with Norbert Roozenburg, who was just completing his own book on design methodology, *Produktontwerpen: Structuur en Methoden*, which I was able to help get published in an English language version (Roozenburg and Eekels, 1995).

In one of our first collaborations, Norbert and I developed a proposal for a workshop on 'Research in Design Thinking', to bring together research in both design cognition and computational modelling of design processes - i.e. studies of the natural and the artificial intelligence of design. The workshop brought together about a dozen researchers from The Netherlands, Germany, the UK and the USA, and was held in Delft in May 1991. The workshop and its proceedings (Cross, Dorst and Roozenburg, 1992) launched the beginning of a new phase of research for me in designerly ways of knowing and the science of design. It also launched a number of further workshops and conferences that became the series of Design Thinking Research Symposia (DTRS).

Kees Dorst and Henri Christiaans, who were both working on protocol studies of designer behaviour for their PhDs at Delft, returned from presenting a joint paper at the ASME Design Methodology conference in the USA in 1992 with a proposal for another workshop. The proposal had originated at the ASME meeting in their discussions with David Radcliffe (University of Queensland, Australia) and Scott Minneman (Xerox Palo Alto Research Center, USA). The idea was to use facilities at Xerox PARC to video-record experiments with both individual designers and small teams tackling the same design problem, and then invite researchers around the world to analyse these recordings and present their studies at another workshop to be held in Delft. The Faculty of Industrial Design Engineering again gave financial support, and Xerox PARC provided the facilities; Larry Leifer and his engineering design group at Stanford University in Palo Alto also provided contacts with local designers who volunteered to be our experiment participants. Kees and Henri worked up the design of the experiment, including the design brief and background information for 'a device for carrying a backpack on a mountain bike', and we spent a week at Xerox PARC in January 1994 conducting and recording the experiments with Scott Minneman and his colleague Steve Harrison. From the half-dozen sessions we ran, we selected the recordings of one individual designer (the engineering designer Victor Scheinman from Stanford) and one team of three (product designers from the IDEO design consultancy in Palo Alto) as the common data sets. The international workshop held in Delft later that year became the 'Delft Protocols Workshop', with some 20 papers being presented. That meeting, and the book of proceedings on *Analysing Design Activity* (Cross, Christiaans and Dorst, 1996), firmly established both a programme of research in design thinking and protocol analysis as a principal research method.

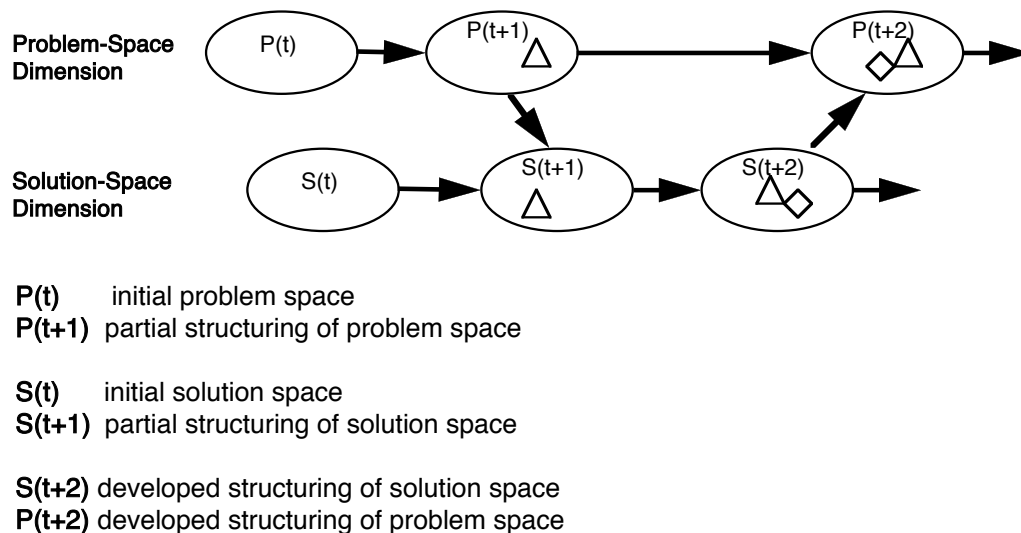
At the workshop, Ömer Akin, from Carnegie Mellon University, expressed the view that it had been a great success and that he would like to organise another - which he did, in Istanbul in 1996 on 'Descriptive Models of Design'. And so a series of meetings had started, and also the informal way in which it has continued, with each meeting somehow generating a proposal for the next. It was Gabi Goldschmidt and William Porter who coined the generic name 'Design Thinking Research Symposia' (DTRS), at the next meeting, at MIT in 1999. The eleventh Design Thinking Research Symposium, held in Denmark in 2016, marked the 25th anniversary of the start of the symposium series. So the series started rather by accident, and also continued by a rather accidental process of enthusiasm for 'what next?' and the creativity and goodwill of volunteers intent on making it happen. But overlaying its accidental nature there has been serious academic purpose and a concern for ensuring good research that helps knowledge to grow and disseminate. Together, the organisers and participants created an international 'invisible college' to promote and sustain research in design thinking. The DTRS series has produced a substantial set of publications in books and journals (see Cross, 2018a), with significant research results, and has helped to generate and foster a community of scholars and researchers with interests in design cognition.

One of my own pieces of research arose from the Delft Protocols Workshop, in an analysis of how creative thinking happens in design. The conventional idea of a 'creative leap', in which a novel concept emerges quite suddenly as a potential design solution, is widely regarded as a characteristic feature of creative design. My analysis (Cross, 1997) was based on an example of a key creative moment that occurred during the design team's work, when one of the team members proposed a 'plastic tray' concept for the device, which became the basis of their final design. I concluded, from the evidence for the development of that key moment, that the cognitive act underlying

creative insight in design is not so much taking a 'leap', from problem to solution, but more akin to proposing a 'bridging' structure between problem space and solution space. Such a 'creative bridge' creates a resolution between the unfolding design requirements and the emerging design structure of a potential new product.

Kees Dorst and I developed this idea further in a later paper (Dorst and Cross, 2001), based on the series of protocol studies that Kees undertook with experienced industrial designers, all tackling the same problem. In this paper, we applied a prior AI model (from Maher and Poon, 1996) of the co-evolution of problem/solution spaces to our observations of the designers. We modelled creative design in terms of the bridging of problem and solution spaces and their co-evolution within the design process towards a matching pair. Figure 3 models what we observed in the experiments.

The co-evolution model fits well with the abductive or appositional nature of design thinking, in that it embodies the building of emergent relationships between problem and solution. This paper established the concept of co-evolution as a significant distinguishing feature of creative design activity, and it has been used subsequently by many other design researchers.

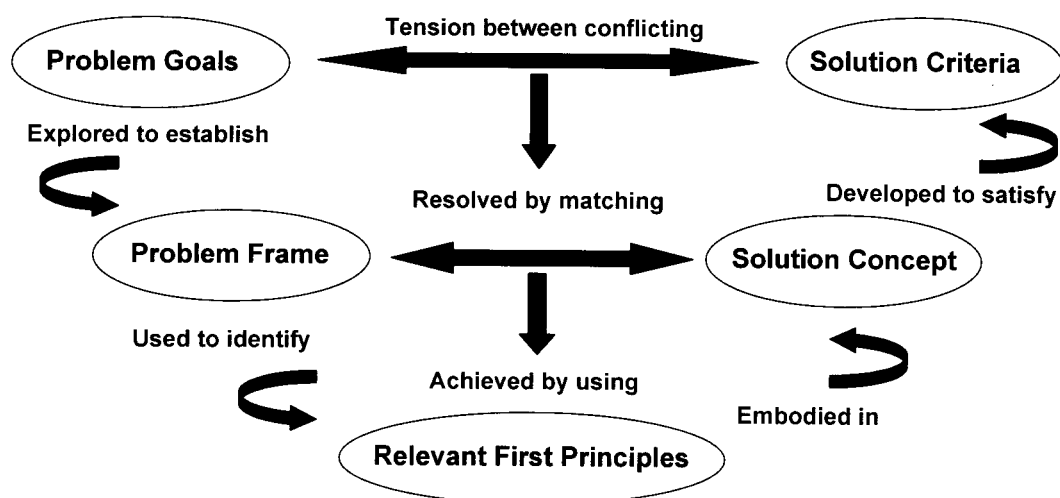


*Figure 3*

A model of the co-evolution of problem and solution in design. Designers start by exploring the problem space (PS), and find, discover, or recognise a partial structure (P(t+1)). That partial structure is then used to provide them with a partial structuring of the solution space (SS) (S(t+1)). They consider the implications of the partial structure within the SS, use it to generate some initial ideas for the form of a design concept, and so extend and develop the partial structuring (S(t+2)). They transfer the developed partial solution structure back into the PS (P(t+2)), and again consider implications and extend the structuring of the PS. Their goal is to create a matching problem-solution pair. (Dorst and Cross, 2001)

These kinds of studies were part of a programme of trying to understand the design strategies of experienced and even outstanding designers. Previously, most studies of designer behaviour had been based on novices (e.g. students) or, at best, designers of relatively modest talents. The reason for this, of course, is that it is easier to obtain such people as subjects for study. However, if studies of designer behaviour are limited to studies of rather inexpert designers, then it is also obvious that our understanding of expertise in design will also be limited. In order to understand expertise in design, we must study expert designers and, if possible, study exceptionally good designers.

One such outstanding designer was the engineer Victor Scheinman, whom we had the good fortune to obtain as a participant in the Delft Protocols study. Another two to whom I had privileged access were personal friends, Gordon Murray, the Formula One race car designer, and Kenneth Grange, the industrial product designer. Both of these are outstanding designers in their fields, and both were willing to talk about and demonstrate their design tactics and strategies. These three expert designers have featured in a number of papers directed towards investigating the nature of design expertise (Cross and Clayburn Cross, 1998; Cross, 2002). There appear to be several striking similarities in the creative strategies exercised by these designers working across very different fields, which suggest that a common understanding, and indeed a general model might be constructed of high level, creative strategies in design. I developed a general descriptive model from the examples (Figure 4), showing how strategic knowledge in creative design is exercised at three levels: low level articulated knowledge of first principles, an intermediate level of tacit personal and situated knowledge applied within the particular problem and its context, and high level implicit and explicit knowledge of problem goals and criteria. All three outstanding designers that I studied seem to exercise this strategic knowledge in similar ways in creating novel design proposals. In summary, creative design begins with a tension between the problem goals and criteria for a satisfactory solution; this is resolved by matching a problem frame with a solution concept; which is achieved by drawing on relevant first principles.



*Figure 4*

A model that generalises the strategic approaches found in the work of outstanding designers. At the lower level is knowledge of first principles, which may be domain specific or more general scientific knowledge. At the intermediate level is where strategic knowledge is especially exercised, and where that knowledge is more variable, situated in the particular problem and its context, tacit and perhaps personalised and idiosyncratic. At the higher level there is a mix of relatively stable, but usually implicit goals held by the designer, the temporary problem goals, and explicit solution criteria specified by the client or other domain authority. (Cross, 2002)

I also wrote a paper that provided an overview of what had been learned from protocol and other empirical studies of design activity, and summarised results relevant to

understanding the nature of design cognition from an interdisciplinary, domain-independent perspective (Cross, 2001b). The results were presented grouped into three major aspects of design cognition – the formulation of problems, the generation of solutions, and the utilisation of design process strategies. I drew parallels and comparisons between results, and found many similarities of design cognition across domains of professional practice. Perhaps the most interesting conclusion was that it seems that the 'intuitive' behaviour (actually, experienced behaviour) of designers is often highly appropriate to the special nature of design tasks, although appearing to be 'unprincipled' (or unsystematic) in theory.

In 2003 Ernest Edmonds offered to host one of the DTRS series at the University of Technology, Sydney, Australia, specifically focused on expertise in design, for which I prepared a review paper on expertise in general and especially expertise in design (Cross, 2004). In doing this, I was returning to the concept of 'designerly ways of knowing' and attempting to understand and articulate what constitutes the particular nature of expertise in design. Much of my work on design cognition is brought together in the book *Design Thinking: Understanding how designers think and work* (Cross, 2011).

I have continued to develop an evidence-based understanding of design expertise, recently contributing a chapter on 'Expertise in Professional Design' to the *Cambridge Handbook of Expertise and Expert Performance*. In that chapter I concluded that

Expert designers appear to be 'ill-behaved' problem solvers, e.g. in that they do not devote extensive time and attention to defining the problem. However, it seems that this may well be appropriate behaviour, since some studies have suggested that over-concentration on problem definition does not necessarily lead to successful design outcomes. It appears that successful design behaviour is based not on extensive problem analysis, but on adequate 'problem scoping' and on a focused or directed approach to gathering problem information, prioritising criteria and generating solution concepts. Setting and changing goals, rather than sticking to the problem as given, are inherent elements of design activity.

Expert designers perform in ways akin to other professionals ... dealing with practical situations of uncertainty, inadequate information and unclear goals ... Like other professional decision makers, expert designers do not work from 'intuition' but have recognisable and appropriate strategies for dealing with their ill-defined problems, as research in understanding design expertise has shown. (Cross, 2018b, p. 386)

Perhaps finally I have begun to understand a little more about 'how to design'!

The general progression of my work, from design computing and methodology to design epistemology and cognition, has been a development from aiding and improving design practice towards a more fundamental understanding of the nature of skilled design practice. This progression began from a pragmatic necessity to explore the concept of design as a discipline, because I had been appointed to something called the 'Design Discipline' at the Open University. At that time (and probably still today) there were people who were adamant that 'design is not a discipline', but I believe it now to be widely accepted that design is developing strongly as an academic discipline, as well as a professional practice. It was following the idea of design as a discipline that led me into studies of how designers think and work. The later studies of expert and outstanding designers have been a fundamental personal re-orientation away from the early design science of CAD and design methodology towards a science of design based on design epistemology, cognition and praxiology, necessary to underpin design as a discipline. My guiding principle has been that the design community must be able to



hold a defensible, evidence-based, core paradigm of designerly ways of knowing, thinking and acting.

## Epilogue

Looking back over 50 years of my involvement in design research, the achievements seem to be rather modest. But younger design researchers today must find it difficult to imagine our field as it was in the early 1960s, as the new approaches and attitudes to design began to appear. There were none of the journals we now have; no design research conferences; no Design Research Society nor Design Society; no PhD programmes in design; no concept of design as a discipline; even no design in engineering education!

I was fortunate to be in at the beginning of things that pioneers such as Chris Jones and Bruce Archer started. I was fortunate to be in at the beginning of the 'Design Discipline' at the Open University, and to be faced with the challenge of re-inventing design education. I was fortunate to be able to lead the OU's Design Discipline - later to become the Department of Design and Innovation - for a long period through the 1980s and into the 1990s, during which we became one of the leading new departments of design in the UK, in both teaching and research. I was fortunate to be able to develop a strong working relationship with colleagues in the Faculty of Industrial Design Engineering at Delft University of Technology in the 1990s, which opened new opportunities for research in design thinking. I was also fortunate to be an editor of the journal of *Design Studies* from its inception, and thus able to encourage, promote and disseminate good research.

Those of us with long memories know that many new techniques, methods and approaches in design practice - ranging from design methods to computer modelling and virtual reality - originated in design research. It seems that it takes a generation, at least twenty-five years, maybe thirty years or more, for the things that perhaps seemed 'ivory tower' research projects and ideas to become embedded in practice. Usually, the practitioners don't realise that what they are doing or using is something that originated within the design research community. Often, contemporary observers and commentators don't realise that either, because of course the practitioners don't reference their work back to its origins.

However, the aims and objectives of design research are not just focused on applications for design practice; there are also many other kinds of achievement of which to be proud. Especially, research also feeds into education. One of the significant achievements of design research has been what it has contributed to the broadening of design education beyond apprenticeship and technical training; the understanding that has grown of the nature and relevance of design thinking. Design graduates are now better educated; more self-aware about designing and the design process, how to be a designer and the contribution designers make to society. Even beyond that, developing design as a discipline has made it possible for design to interact with many other disciplines, from computing science to cognitive science, anthropology to psychology, management to philosophy.

Looking forward, we could do with some consolidation and focused development of what has been achieved in the 50 years of design research. At a pragmatic level, I am thinking especially of meta-analyses, review articles, etc., and books that genuinely, comprehensively and thoughtfully present the state-of-the art. (There are some books

with 'Design Research' in their titles that are travesties.) In PhD research in design, we need better, more focused research training and, instead of seeking novelty, there could be some useful attention to either confirming or refuting some of the early, single-case studies that are still relied upon as foundational evidence within our discipline. More broadly, I think the discipline of design could benefit from a much more progressive and coordinated research programme, rather than the fragmentation that seems evident today. It needs a solid, collective viewpoint instead of idiosyncratic, personal views of what constitutes design research; it needs significant leadership and an honest acknowledgement from people within the field that we are all still novices in design research.

## References

- Alexander, C. 1964. *Notes on the Synthesis of Form*. Harvard University Press: Cambridge, MA, USA.
- Alexiou, K., Zamenopoulos, T., Johnson, J and Gilbert, S. J. 2009. 'Exploring the neurological basis of design cognition using brain imaging: some preliminary results', *Design Studies* (30) 623-647.
- Archer, L. B. 1965. *Systematic Method for Designers*. The Design Council: London.
- Archer, L. B. (ed.) 1979a. *Design in General Education*. Department of Design Research, Royal College of Art: London.
- Archer, L. B. 1979b. 'Whatever became of design methodology? The three Rs', *Design Studies* (11) 17-20.
- Bucciarelli, L. 1994. *Designing Engineers*. MIT Press: Cambridge, MA, USA.
- Cross, A. C. 1984. 'Towards an understanding of the intrinsic values of design education'. *Design Studies* (5) 31-39.
- Cross, A. C. 1986. 'Design Intelligence: the use of codes and language systems in design'. *Design Studies* (7) 14-19.
- Cross, N. 1972a. 'Impact of computers on the architectural design process', *Architects Journal*, 22 March, 623-628.
- Cross, N. (ed.) 1972b. *Design Participation*. Academy Editions: London.
- Cross, N. 1974. Human and Machine Roles in Computer Aided Design, *PhD Thesis*. University of Manchester.
- Cross, N. 1977a. *The Automated Architect: human and machine roles in design*. Pion: London.
- Cross, N. 1977b. 'Problems of computer aided design', *RIBA Journal*, October.
- Cross, N. 1982. 'Designerly ways of knowing', *Design Studies* (3) 221-227.
- Cross, N. (ed.) 1984. *Developments In Design Methodology*. John Wiley and Sons: Chichester, UK.
- Cross, N. 1989. *Engineering Design Methods*. John Wiley & Sons: Chichester, UK.
- Cross, N. 1990. 'The nature and nurture of design ability', *Design Studies* (11) 127-140.
- Cross, N. 1993. 'Science and design methodology: a review', *Research in Engineering Design* (5) 63-69.
- Cross, N. 1997. 'Descriptive models of creative design: application to an example', *Design*

*Studies* (18) 427–440.

Cross, N. 1999. 'Natural intelligence in design', *Design Studies* (20) 25-39.

Cross, N. 2001a. 'Can a machine design?', *Design Issues* (17) 44-50.

Cross, N. 2001b. 'Design Cognition: results from protocol and other empirical studies of design activity'. In C. Eastman, M. McCracken and W. Newstatter (eds.) *Design Knowing and Learning: Cognition in Design Education*, 79-103. Elsevier: Oxford, UK.

Cross, N. 2001c. 'Designerly ways of knowing: design discipline versus design science' *Design Issues* (17) 49-55.

Cross, N. 2002. 'Creative Cognition in Design: processes of exceptional designers'. In T. Hewett and T. Kavanagh (eds.) *Creativity and Cognition*, 14-19. ACM Press: New York.

Cross, N. 2004. 'Expertise in design: An overview', *Design Studies* (25) 427-441.

Cross, N. 2006. *Designerly Ways of Knowing*. Springer: London.

Cross, N. 2007. *Designerly Ways of Knowing*, Birkhauser: Basel, Switzerland.

Cross, N. 2008. *Engineering Design Methods: Strategies for Product Design* (4<sup>th</sup> ed.). John Wiley & Sons: Chichester, UK.

Cross, N. 2011. *Design Thinking: Understanding how Designers Think and Work*. Berg/Bloomsbury: London.

Cross, N. 2018a. 'A brief history of the Design Thinking Research Symposia series', *Design Studies* (57) 160-164.

Cross, N. 2018b. 'Expertise in Professional Design', in K. Anders Ericsson, R. Hoffman, A. Kozbelt, A. M. Williams (eds.) *Cambridge Handbook of Expertise and Expert Performance* (2<sup>nd</sup> Edition), 327-388. Cambridge University Press: Cambridge UK and New York USA.

Cross, N., Christiaans, H. and Dorst, K. (eds.) 1996. *Analysing Design Activity*. John Wiley & Sons: Chichester, UK.

Cross, N. and Clayburn Cross, A. 1998. 'Expertise in engineering design', *Research in Engineering Design* (10) 141-149.

Cross, N, Dorst, K. and Roozenburg, N. (eds.) 1992. *Research in Design Thinking*. Delft University Press: Delft, The Netherlands.

Cross, N. and Roozenburg, N. 1992. 'Modelling the design process in engineering and in architecture', *Journal of Engineering Design* (3) 325-337.

Cross N, and Roy, R. 1975. *Design Methods Manual*. Open University Press: Milton Keynes, UK.

Dong, A. 2009. *The Language of Design: Theory and computation*. Springer-Verlag: London.

Dorst, K. and Cross, N. 2001. 'Creativity in the design process: co-evolution of problem-solution', *Design Studies* (22) 425-437.

Gardner, H. 1983. *Frames of Mind: The theory of multiple intelligences*. Heinemann: London.

Gero, J. S. 1990 'Design prototypes: A knowledge representation schema for design', *AI Magazine* (11) 26-36.

Goel, V. 1995. *Sketches of Thought*. MIT Press: Cambridge, MA, USA.

Goel, V. and Grafman, J. 2000. 'Role of the right prefrontal cortex in ill-structured planning', *Cognitive Neuropsychology* (17) 415-436.

Goldschmidt, G. 1991. 'The dialectics of sketching', *Creativity Research Journal* (4) 123-143.

Jones, J. C. 1970. *Design Methods*. John Wiley & Sons: Chichester, UK.

- Jones, J. C. and Thornley, D. G. (eds.) 1963. *Conference on Design Methods*. Pergamon Press: Oxford, UK.
- Lawson, B. 1980. *How Designers Think*. Architectural Press: Oxford, UK.
- Lawson, B. 1994. *Design In Mind*. Architectural Press: Oxford, UK.
- Lawson, B. and Dorst, K. 2009. *Design Expertise*. Architectural Press, Oxford, UK.
- Maher, M. L. and Poon, J. 1996. 'Modeling design exploration as co-evolution', *Computer-Aided Civil and Infrastructure Engineering* (11) 195–209.
- Nadler, G. 1980. 'A timeline theory of planning and design', *Design Studies* (1) 299-307.
- Negroponte, N. 1970. *The Architecture Machine*. MIT Press: Cambridge, MA, USA.
- Purcell, A. T. (ed.) 1998. Special Issue on Drawings and the Design Process, *Design Studies* (19).
- Roozenburg, N. and Eekels, J. 1995. *Product Design: Fundamentals and Methods*. John Wiley & Sons: Chichester, UK.
- Schön, D. 1983. *The Reflective Practitioner: How Professionals Think in Action*. Temple Smith: London.
- Schön, D. and Wiggins, G. 1992. 'Kinds of seeing and their functions in designing', *Design Studies* (13) 135-156.
- Simon, H. A. 1969. *The Sciences of the Artificial*. MIT Press: Cambridge, MA, USA.
- Visser, W. 2006. *The Cognitive Artifacts of Designing*. Lawrence Erlbaum Associates: Mahwah, NJ, USA.